II.4 SECA Solid Oxide Fuel Cell Power Plant System Cost Reduction

Objectives

Specific cost-related objectives for this project include:

- Scale up existing SOFC cell area and stack size (number of cells) within a building block unit and stack tower to minimize cost.
- Scale up existing manufacturing infrastructure and capabilities for SOFC cell and stack production on a cost-effective basis.
- Increase SOFC cell and stack performance to maximize power and efficiency for reduced cost on a per kilowatt basis.
- Power block unit system cost goal is to be <$400/kW.

Approach

The project is organized in three phases according to schedule, technical and cost objectives. Following is a short description of the approach as it relates to cost:

- Phase I of the DOE-managed SECA program will focus on cell and stack development activities. This will include scale up of existing SOFC cell area and stack size (number of cells) and performance improvements. The Phase I deliverable for the 3-10 kW development project will be test demonstration of a 3 kW power block system that meets all DOE performance and cost metrics. This includes demonstration of system peak power performance that will be used as the basis for cost. The DOE specified metric for the Phase I 10 kW system factory cost must be less than $800/kWe. The Phase I deliverable for the Coal-Based, large-scale SOFC project will be a test demonstration of a representative SOFC stack building block unit on simulated coal syngas. The system cost, exclusive of the coal gasification and CO_2 separation subsystems, must be $600/kWe or less at the end of the Phase I project.
- Phase II of the Coal-Based project will focus on modularization of the Phase I stack building block units into MW-size modules. Detailed design engineering and analysis for multi-MW power plant systems will be conducted. The Phase II deliverable will be a test demonstration of a MW-size representative SOFC stack module on simulated coal syngas. Phase II system cost, exclusive of the coal gasification and CO_2 separation subsystems, must be $400/kWe or less at the end of Phase II, and is applicable to both the baseline (>100 MWe) system and the proposed Phase III proof-of-concept system. The cost estimate must establish and fully justify a reasonable estimate of the number of systems and their respective size that must be manufactured per year to support this cost goal. An independent audit of the Phase II cost report will be required.
- Phase III of the Coal-Based project will focus on design and fabrication of a proof-of-concept multi-MW power plant including turbine for high efficiency and CO_2 separation for low emissions. Phase III system cost objectives are the same as in Phase II. The Phase III deliverable will be long-term testing of a multi-MW size power plant at a site selected for FutureGen.

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Accomplishments

- Increased SOFC cell area and number of cells per stack building block unit resulting in ~5-fold increase in stack volumetric power output from early generation stacks units.
- Completed SECA Phase I 3 kW SOFC stack and system test demonstration validating performance of the scaled-up components. This test validation included successful demonstration at the peak power performance used to calculate system cost.
- Developed preliminary factory cost bill-of-materials (BOM) for stack and 3 kW system for DOE third party audit validation. Estimated stack and system costs for the 3 kW unit meets DOE metric for the Phase I project.

Introduction

Fuel Cell Energy, Inc. (FCE) has been engaged in a Department of Energy (DOE)-managed SECA Phase I project to develop a 3-10 kW SOFC power plant system since April, 2003. FCE has recently been selected by DOE to participate in a multi-phase project for development of very efficient coal to electricity, large scale (multi-MW) power plants with near zero-emissions. This new project's technical objectives will be merged with the existing 3-10 kW project's Phase I technical objectives based on similarities for cell and stack development. The primary objectives of these projects are to develop affordable, SOFC based power plant systems with high efficiency that are cost competitive with other power generating technologies of similar capacity without incentive funding support. In order to be cost competitive with other power generating technologies of similar capacity without the need for incentive funding programs, significant SOFC stack and system cost reduction must occur from the current low volume development level to high volume, mass production prices. The achievement of the program cost targets is a key facet of the SECA projects. FCE is ideally suited for these projects based on experience with cost reduction successes for their commercial fuel cell power plants now being installed worldwide. FCE will use the cell and stack design of their SOFC technology partner, Versa Power Systems, Inc (VPS) as the basis for these projects. VPS has been actively engaged in cost effective SOFC manufacturing process research and development since 1998 and has well establish processes, quality procedures and equipment for the manufacture of small to intermediate size cells and stacks as depicted in Figure 1. The DOE-specified metric for the final program system cost determined to be competitive with other power generating technologies of similar capacity without incentive funding is <$400/kW for a multi-MW power plant, exclusive of coal gasification and CO_2 separation subsystem costs.

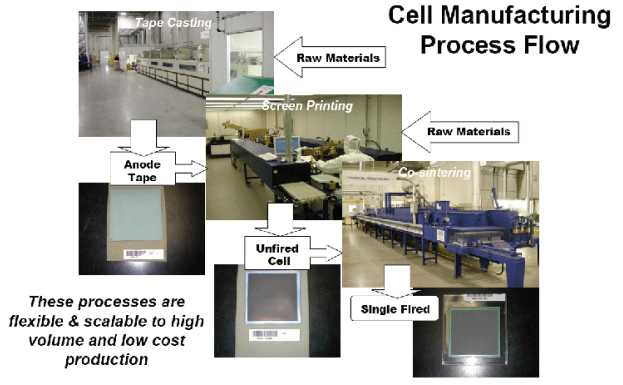

FIGURE 1. Versa Power Systems SOFC Manufacturing

Approach

The path forward for development of cost competitive SOFC power block systems includes a multi-faceted approach for both SOFC stack module design as well as system balance-of-plant (BOP) development. The technical approach consists of an innovative fuel cell stack configuration, fabrication of scaled-up cells, newly developed fuel cell seals, novel implementation of a fuel cell clustering concept and integration of SOFC clusters with a gas turbine. The future development plans include investigation of both fabrication and operational issues related to scale-up of the fuel cell active area. For the Coal-Based project, an innovative and patented power cycle will be utilized to achieve very high efficiencies by integration of the fuel cell with an indirectly heated gas turbine. The power plant design is projected to have a factory cost of $400/kW, based on a production capacity of about 1.4 GW/year or twelve 120 MW power plants per year. This cost is very competitive with today's cost of combined cycle technologies.

The project is organized in three phases according to schedule, technical and cost objectives. Details for the three phases are as follows:

- Phase I (2-3 years):
  - Scale up SOFC cell area and stack height (number of cells) and improve performance.
  - Design a baseline system that meets the project technical objectives.
  - Ensure stack and power plant designs are consistent with a projected cost of $800/kW for the 10 kW development project, and $600/kW for the large scale Coal-Based project.
  - Fabricate and validation test representative stack building block units under simulated commercial operational conditions.
- Phase II (2 years):
  - Develop a detailed design and cost analysis for the proposed power plant system that meets project objectives.
  - Ensure stack and power plant design are consistent with a projected cost of $400/kW for a multi-MW system (exclusive of coal gasification and CO_2 separation subsystem costs) for the Coal-Based project.
  - Fabricate and validation test a representative fuel cell module building block unit for the multi-MW power plant on simulated coal syngas.
- Phase II (5 years):
  - Complete detailed design for multi-MW power plant system that meets project performance and cost objectives. Cost objectives are the same as in Phase II.

- Procure and fabricate SOFC stack and system components and assemble proof-of-concept multi-MW power plant system including gas turbine (>1 MW).
- Locate coal gasifier site and integrate multi-MW power plant.
- Conduct long-term (~25,000 hours) test demonstration of multi-MW power plant system on coal based syngas meeting project technical objectives for performance (power, efficiency), durability (load transients and thermal cycles), degradation and cost.

Results

FCE has been engaged in a DOE-managed SECA Phase I project to develop a 3-10 kW SOFC power plant system since April, 2003. Much progress has been made in the SECA Phase I project on cell and stack scale-up, increased performance and cost reduction. A detail factory cost estimate analysis and report for a 3-10 kW stack and system was submitted and audited by DOE selected auditors. Results indicate the total 3-10 kW system cost estimated to be $773/kW based upon an annual production rate of 50,000 units and a peak power rating of 5.37 kW. This is less than the SECA Phase I metric of $800/kW using the same assumptions. As shown in Figure 2, the stack accounts for ~16% of the total system cost, while the BOP components account for ~73% of the cost. The remainder of the system cost (~11%) is associated with building, commissioning and testing (BC&T) of the power block unit. The low cost associated with the stack reflects the many years of process development and cost reduction activities at VPS. The current cell manufacturing process has three major fabrication operations for anode-supported planar cells: tape casting, screen-printing and co-firing (TSC) as shown in Figure 1. The TSC process is a fully integrated cell manufacturing process. Major process improvements have resulted in reduced process steps (number of sinter firings) with an associated reduction in costs. Figure 3 shows that such process improvements have resulted in ~65% cost reduction while overall yields have improved by ~40%. All major manufacturing and process steps have been demonstrated to be cost-effective by the semiconductor packaging and multi-layer capacitor industries. The TSC process can be further engineered into repeatable mass manufacturing modules for additional product cost savings. Economies of scale and automation will provide the greatest effect on cell equipment cost. Scale-up of SOFC cell area and number of cells per building block unit was continued in the SECA Phase I project, culminating in an approximate 5-fold increase in stack volumetric power density as shown in Figure 4. Technology developments that result in decreased material usage have also contributed significantly to reduced cell component cost. Figure 5 shows a 51% cost savings attributed to decreasing the thickness of the SOFC active cell component. While the majority of the system cost is associated with the BOP,

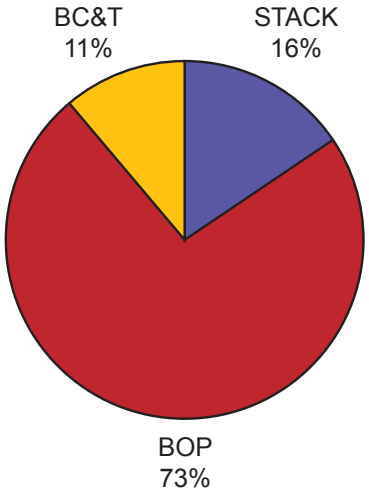

FIGURE 2. SECA Phase I 3-10 kW SOFC System Costs Breakdown

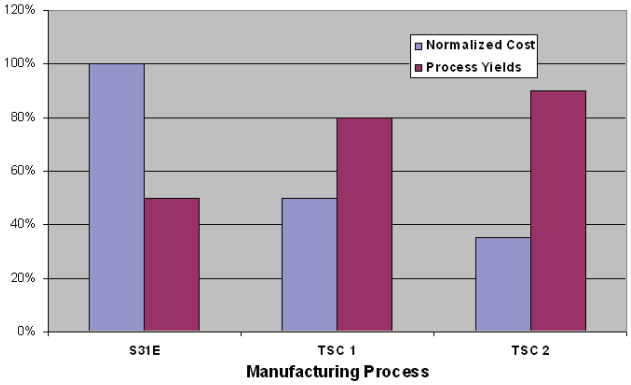

FIGURE 3. SOFC Cell Manufacturing Process Improvements

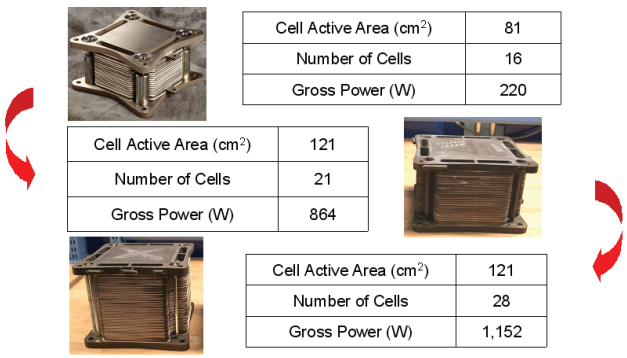

FIGURE 4. SOFC Scale-Up SECA Phase I Program Accomplishments

this is the area that presents the greatest opportunity for further cost reduction. Greater than 75% of the BOP costs are procured components. Once a design configuration is stabilized to enable volume pricing, multiple vendor sourcing is established and value-engineering programs are in play, it is anticipated that significant cost savings (>50%) will be realized. As the power plant size becomes larger, the BOP and associated costs will also diminish proportionally on a cost-per-kilowatt basis. This provides the greatest cost reduction opportunity for the Coal-Based, multi-MW sized power plants to be developed in the new program. Finally, technology improvements focused on enhanced cell power output will be a major driver in reducing power plant system costs. Figure 6 presents improvements in cell power density output on a normalized basis developed by VPS over the years and continued in the SECA Phase I project. As can be seen, ~2-fold increase in power density is expected over the current state-of-the-art technology for the pre-commercial power block units. This peak power performance operation was demonstrated with the SECA phase I, 3 kW system test. The high power density operation was executed at the end of the 3-1 system test period, with stacks that had operated for greater than 2,000 hours including multiple load transients and thermal cycles providing confidence in achieving this milestone performance goal.

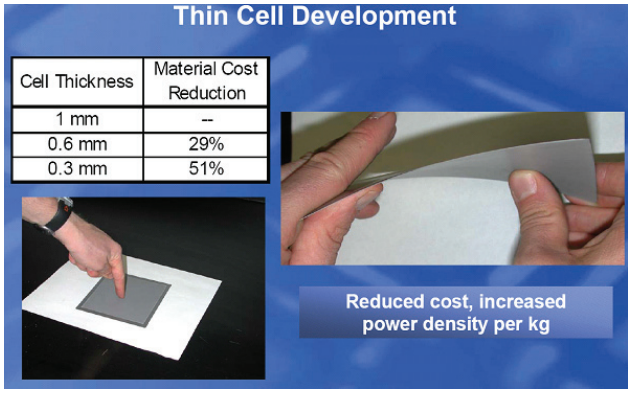

FIGURE 5. SOFC Cell Thickness and Material Reduction

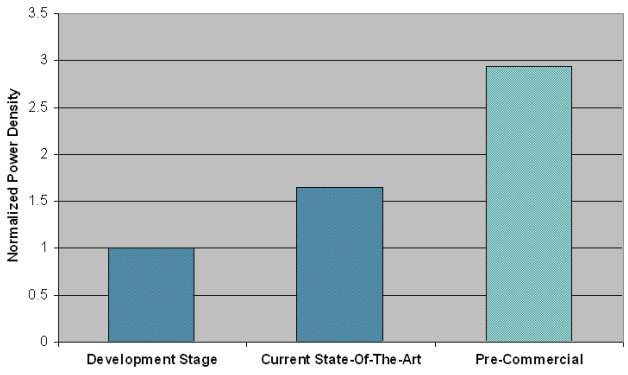

FIGURE 6. SECA 3kW SOFC Cell Performance Improvement

Summary

- FCE has been engaged in a DOE-managed SECA Phase I project to develop a 3-10 kW SOFC power plant system since April, 2003. FCE has recently been selected by DOE to participate in a multi-phase project for development of very efficient, large scale (multi-MW) coal to electricity power plants with near zero-emissions with similar SOFC cell and stack development and cost objectives.
- The primary objectives of these projects are to develop affordable, SOFC-based power plant systems with high efficiency that are cost-competitive with other power generating technologies of similar capacity without incentive funding support.
- FCE is ideally suited for these projects based on their cost reduction experience with commercial fuel cell power plants now being installed worldwide and the successes of their SOFC technology partner, VPS, with SOFC cell and stack manufacturing development and operational performance.
- Accomplishments in FCE's SECA 3-10 kW development Phase I project include expanded manufacturing process capabilities, scale-up of SOFC cell area and stack height and improved performance resulting in ~5-fold increase in volumetric power density.
- Completed SECA Phase I 3 kW SOFC test demonstration of a system that contained scaled-up cell and stack units as final validation of the scale-up process and components. Peak power performance was demonstrated that will be used for the cost of electricity basis.
- The FCE team developed a preliminary factory cost bill-of-materials (BOM) for stack and 3 kW system to be audited by DOE third party expert. Stack and system costs are below SECA Phase I program requirements.

FY 2006 Publications/Presentations

1. "Coal Based Large SOFC/T Systems", H. Ghezel-Ayagh, J. Doyon, Fuel Cell Energy Inc. Paper presented at the 2006 Fuel Cell Seminar on November 13-17, 2006, Honolulu, Hawaii.

2. "Development of Solid Oxide Fuel Cells at Versa Power Systems", B. Borglum, E. Tang, M. Pastula, J. Kelsall, R. Petri, Versa Power Systems. Paper and presentation at the 2006 Fuel Cell Seminar on November 13-17, 2006, Honolulu, Hawaii.

3. "SOFC Development Status at Versa Power Systems, Inc.", B. Borglum, Versa Power Systems. Presentation at the 2006 Lucerne Fuel Cell Forum, July 4, 2006.